Astronomy and Calendars – The Other Chinese Mathematics

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104 BC–AD 1644

Springer

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The author is an honorary Director of Research. After the publication of the French version of the present book (2009), he has been awarded in 2010 the Ikuo Hirayama prize by the Académie des Inscriptions et Belles-Lettres for the totality of his work on Chinese mathematics.

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Omnem movere lapidem
(To leave no stone unturned)
D. Erasmus, *Adagiorum collectanea*,
Paris, 1506-1507, I-4-30

To France

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ACKNOWLEDGEMENTS

The idea at the origin of this study of the Chinese calendar and its calculations was sparked by the observation that surprisingly little research has been conducted into this domain until now, but it is also the consequence of a much more ancient interest in the history of Chinese mathematics and the mathematical aspects of Chinese astronomy. It would not have been completed without the support of the National Center for Scientific Research (CNRS) and other research centers into sinology and the history of science, and without repeated contacts with professionals of these domains all over the world. The professors Jacques Gernet (honorary professor at the Collège de France) and Jean Dhombres (emeritus director of research at the CNRS and head of study at the École Pratique des Hautes Études en Sciences Sociales (EHESS)) have both actively encouraged its realization and it is a pleasure for me to express my gratitude to them in the first place.

In France, the completion of the *Grand dictionnaire Ricci de la langue chinoise* (*Great Ricci Dictionary of the Chinese Language*) (Paris, Desclée de Brouwer, 2001), in which I have been involved for many years as regards Chinese mathematics, astronomy and the calendar, has been an occasion for me of frequent contacts with members and researchers of the Ricci Institute, notably the late Father Claude Larre S.J. and Élisabeth Rochat de la Vallée. These philological works have then stimulated my interest in all sorts of related issues.

Above all, the CNRS team devoted to research into Chinese civilization, where I have worked with other sinologists, has been essential. More particularly, I have been involved in a collaborative research project on divination and society in Medieval China, notably with my colleagues Marc Kalinowski (Head of Study at the École Pratique des Hautes Études (EPHE)) and Alain Arrault (member of the École Française d'Extrême Orient (EFEO)) from 1999 to 2003. On this occasion, we have been lastingly interested in the description, classification and dating of about fifty non-official Chinese manuscript calendars from the Dunhuang collections (781–993) held by the Bibliothèque nationale de France and the British Library, mainly. During these years, I had direct exchanges with many Chinese researchers, invited by our research team or met on the occasion of international congresses, notably the Taiwanese professors Ping-yi Chu (Academia Sinica, history and philology), Daiwie Fu (Tsing-Hua University, history department), Yi-long Huang (Tsing-Hua University, history department and later Academician from the Academia Sinica), Wann-Sheng Horng (Taiwan National University mathematics department) and Deng Wenkuan (Research Institute into the Chinese Cultural Heritage, Beijing). All of them have then kindly answered my queries and have kept me informed of ongoing research into the Chinese calendar or related subjects, connected in one way or another with the history of Chinese mathematics.

During the first week of July 2000, I participated in a conference on calendars in general, organized by the historians of the Middle Ages Jacques Le Goff and Perrine Mane and the mathematician Jean Lefort. Then, the multi-faceted aspects of calendrical time in various cultures have usefully highlighted the similarities and the peculiarities of the Chinese case comparatively with so many other possibilities of calendars. Some time before, regular contacts with Tony Lévy (Hebrew mathematics, CNRS), Pierre-Sylvain Filliozat (Sanskritist, Académie des Inscriptions et Belles-Lettres, CNRS, EPHE), André Cauty (Amerindian linguistics, Bordeaux University) and Jim Ritter (Babylonian mathematics, Paris VIII University) have brought to my attention the problems raised by written numerations and zero in general.

In England, I have visited two times the Needham Research Institute in Cambridge, in December 1997 and December 2005. Christopher Cullen (the present Director of this Institute, successor of Professor G.E.R. Lloyd) and the librarian John Moffett, have facilitated my access to its precious documentation and allowed me to work in particularly favorable conditions. I have also met there the historian of astronomy Raymond Mercier (Cambridge University) in Cambridge and elsewhere.

In China, at Beijing, multiples invitations to the Institute of Mathematics and Systems Science (Academia Sinica) and the continued support of Professor Li Wenlin – whose role in the development of the history of mathematics in contemporary China has been essential – have allowed me to meet, on numerous occasions, Chinese researchers specializing in the history of Chinese mathematics and mathematical astronomy, notably the late Chen Meidong, Liu Dun, Guo Shuchun and Sun Xiaochun. Wang Yusheng too has always been ready to meet efficiently all my requests with an unequaled joviality and receptiveness. In September 1993, I could meet the professors Zhang Peiyu and Li Yong, specialists of Chinese astronomy, at the Nanjing Zijinshan Observatory. At the same time, Professor Xuan Huancan (Nanjing University, Astronomy Department) has kindly forwarded to me recent publications on the subject over many years. At Xi'an and elsewhere, I also have had extensive exchanges with Qu Anjing (Department of Mathematics, Northwest University, Xi'an) and I would like to warmly thank all these researchers and more generally all those who have made my work in China easier.

Lastly, I would like to express my gratitude to the librarians of the Institut des hautes études chinoises, those of the Sorbonne University (Paris) and all the members of the research team devoted to the study of Chinese civilization to which I belong and where I have worked with pleasure and enthusiasm for so many years.

ABBREVIATIONS AND CONVENTIONS

General Abbreviations

–	indicates a negative year;
.	As usual, a dot is used to separate the integer and fractional part of a decimal number. Not to be confused with other similar notations, introduced in Chapter 3 of this work and only concerning non-decimal numbers used in Chinese calendrical calculations;
j.	*juan*, book chapter (sometimes 'book'), literal meaning :'roll', an allusion to antique Chinese books, similar to the *volumina* of Greek and Roman Antiquity.

Bibliographical Notations

*	When a book has been edited several times, an asterisk marks the years of publication of the consulted versions;
-	When the publication of some work extends over several years, its initial and final years are separated by a dash;
/	Slash between the various years of edition of a work published several times;

Other Abbreviations

abbrev.	abbreviation
Ar.	Arabic
astron.	'astronomy' or 'astronomical'
ca.	Latin: circa. Means 'approximately'
cal.	calendar(s) or calendrical
Chin.	Chinese

denom	denominator
Eng.	English
f.	after a page number means ‘and the following pages’ (also noted ‘ff.’ in other works)
fl.	floruit. Indicates when somebody was active (Latin: flourished).
Heb.	Hebrew
Jap.	Japanese
Lat.	Latin
ms.	manuscript
numer	numerator
proc.	procedure(s)
Skr.	Sanskrit
transl.	translation

Lunar Phases and Special Months

FM	full moon;
FQ	first quarter;
LQ	last quarter;
NM	new moon (also very often noted n_i for some i);
m_{an}	anomalistic month
m_{syn}	synodic month

Reference Works

COLL.	collective work;
COL-astron	*Zhongguo kexue jishu dianji tonghui*, *tianwen juan* 中國科學技術典籍通彙,天文卷 (*General Collection of Chinese Scientific and Technical Works*, *Astronomy*), 1993 (full reference p. 390);
COL-math	same reference but for mathematics (see also p. 390);

DENG-2002 DENG Wenkuan, *Dunhuang Tulufan tianwen lifa yanjiu* 敦煌吐魯番天文曆法研究 (*Research into Calendars and Astronomy from Dunhuang and Turfan*), Lanzhou, Gansu Jiaoyu Chubanshe 甘肅教育出版社, [collection of articles]

DENG-2010 DENG Wenkuan, 鄧文寬, *Dunhuang tianwen lifa kaosuo* 敦煌天文曆法考索 (*Astronomical Research and Calendar Manuscripts from Dunhuang*) Shanghai, Shanghai Guji Chubanshe 上海古籍出版社, [collection of articles].

DKW Morohashi Tetsuji 諸橋轍次. *Dai kanwa jiten* 大漢和辭典 (*Great Chinese-Japanese Dictionary*), Tokyo, 1960. References to this dictionary are given as follows: volume-page-item number;

LIFA Zhang Peiyu 張培瑜, Chen Meidong 陳美東 et al., 2008. *Zhongguo gudai lifa* 中國古代曆法 (*Ancient Chinese Astronomical Canons*), Zhongguo tianwenxue shi daxi 中國天文學史大系 (*Great Encyclopedia of Chinese Astronomy*), Beijing, Zhongguo Kexue Jishu Chubanshe, 中國科學技術出版社;

SIXIANG Chen Meidong 陳美東, 2008. *Zhongguo gudai tianwenxue sixiang* 中國古代天文學思想 (*Ancient Chinese Astronomical Thinking*), Zhongguo tianwenxue shi daxi 中國天文學史大係 (*Great Encyclopedia of Chinese Astronomy*), Beijing, Zhongguo kexue Jishu Chubanshe, 中國科學技術出版社;

WYG *Yingyin Wenyuange siku quanshu* 影印文淵閣四庫全書 (*Reproduction of the* Siku quanshu *Collection Preserved at the* Wenyuange *Library*), 1500 vol., 1986 (full reference p. 390);

is pinyin

The Transliteration of Chinese

The transliteration of Chinese used here is the *pinyin* phoneticalsystem , a system adopted in 1958 by the Peoplė s Republic of China and now widely accepted all over the world in specialized and non-specialized publications alike, even though the older Wade-Giles system is still rather widespread in the English speaking world.

At the same time, it has been impossible to avoid all sorts of other transcriptions of Chinese names and notions established by custom. But their *pinyin* equivalents or even their original Chinese written forms have also been indicated when necessary.

Chinese Dates

Chinese dates traditionally rely on various and more or less complex formulations. More simply, we have uniformly adopted here the simple format ‘day/lunar month/ lunar year’, where lunar months are denoted by Roman numerals in order to avoid any confusion with Julian or Gregorian dates.

FOREWORD

The study of the ancient Chinese mathematics used for astronomy and the calendar proves that it differs significantly from that of the well-known 'Nine Chapters' tradition. It consist in unceasingly reworked procedures devoted to the prediction of celestial phenomena and the calendar. This study reveals unexpected results, notably, inter alia, non-decimal number systems and a form of written zero not attested elsewhere, the weight of numerology, the strong link between predictive mathematics and divination and the predominance of empirical observation over theory. These results are of interest not only in the history of Chinese mathematics but also, more generally, in the history of science, including astronomy. Furthermore, a comparison between Chinese and non-Chinese ancient approaches reveals both numerous points of contacts and striking dissimilarities, notably a lasting Chinese belief in the impossibility of long-term mathematical predictions. Lastly, numerous examples of calculations support the general description of mathematical patterns underlying calendrical calculations. The present study is a logical extension of my former *A History of Chinese Mathematics* (Springer, 1996 and 2006) and, as such, is primarily intended for readers interested in the cultural history of Chinese mathematics, with or without any sinological background.

Given the multifactorial nature of the history of mathematics, various subjects, which are an integral part of the history of Chinese mathematics, have also been introduced in the first part of the book, notably the influence of politics on mathematics, the Bureau of astronomy, the secret character of astronomical canons, their names, the importance of numerology and divination. However, these various subjects have always been subordinated to the mathematical aspect of the present study, even though each of them could easily have led to the redaction of a sizeable monograph. By committing to this perspective, I have tried to highlight a number of elements generally not taken into account in available histories of Chinese mathematics, notably a piecewise conception of variable phenomena in terms of phases depending on yin-yang conceptions, tests (or quasi-criterions) delivering only probable results, unusual astronomical tables containing not only lists of predetermined coefficients but also terse procedural instructions (‘quasi-tables’), a negative mode of definition – the sole in all extant ancient Chinese mathematics, apparently –, concerning intercalary months. Moreover, beyond punctual peculiarities of this mathematics and, more generally, of Chinese calendrical calculations constituting the core of this work, a broader issue, of interest in the comparative history of science, has also been addressed in order to catch a glimpse of fundamental Chinese conceptions concerning the nature, function and strength of mathematics and the possibility of “laws’ of nature. Starting from a corrected and updated version of its former French version, this book has been modified and organized as follows:

- more importance has been granted to methodological problems (Chapter 1);
- the analysis of the fundamental but difficult notion of *li* 曆, respectively meaning ‘calendar’ in general and ‘mathematical astronomy’, ‘astronomical systems’ or ‘astronomical canons’ in a technical sense, has been significantly developed from a comparative perspective, mainly implying mathematical astronomy from the Islamic and Greek worlds, in the first chapter of this book;
- the analysis of the Chinese belief in the artificial nature of mathematics, and in the impossibility of obtaining immutable predictive techniques based on mathematics, has been reexamined in order to show that, on the contrary, unbounded mathematical predictions were also regarded temporarily as an abstract possibility in the Chinese late medieval and pre-modern context. In the long run, however, the very possibility of obtaining a mathematical formulation of such techniques has continued to be strongly called into question in China;
- the presentation of Chinese mathematical techniques, including those of interpolation and the analysis of solar and lunar tables

has been much more developed. Moreover, the notions of quasi-criterions and quasi-tables have been introduced in order to highlight essential aspects of these other Chinese mathematics;

- a fully worked out example has been added which details the calculation of the dates on which two lunar eclipses occur, recorded in a manuscript calendar for the year 451;

- the bibliographies of primary and secondary sources have been updated in order to take the latest developments (2014) into account;

- last but not least, a large number of further details and new figures have been inserted in various places of the main text. The latter concern, for instance, a Chinese planetary ephemeris, the question of an astronomy without hypotheses, the centesimal system, a schema of an eclipse prediction, the oldest known inscription showing the whole Chinese sexagesimal cycle and, notably, zero.

- a new final section, ‘afterthoughts’, indicates possible directions of interest for future research into the field, concerning, notably, the extension of the present investigation to the mathematical aspects of astronomical canons beyond calendrical calculations, chronological problems and topics concerning more particularly the history of mathematics.

Moreover, like its former version, this book can be used in various ways:

A number of sections can be consulted independently. That is the case for the appendixes and bibliographies, of course. In particular, detailed and updated presentations of almost all available tables of the Chinese calendar, concordance tables and various primary sources have been propounded.

As for the body of the book itself, chapters 1 to 4 are certainly prerequisites but, whereas the first chapter does not involve technical developments and can be read independently, on the contrary, all the notations, definitions and notions introduced in chapters 3 and 4 are constantly used everywhere in the sequel.

More particularly, the fourth chapter grants access to all subsequent developments relying on mean elements which are used in one way or another, exclusively or partly, in all following chapters. In its turn, the fifth chapter introduces true elements (as opposed to mean elements) and related notions intervening in Chinese calendrical calculations. As such it is thus a prerequisite for the examples of calculations developed in the tenth chapter.

The sixth chapter concerns the two latest systems of calendrical calculations (from 1281 to 1644) and the related example of calculations developed at length in the eleventh chapter cannot be read independently.

In the same order of ideas, almost everything contained in the seventh chapter is self-contained, but the examples of related calculations presented in the twelfth chapter also rely on techniques of calculation of mean elements introduced in the fourth chapter.

Lastly, I add that I have entirely composed the French and English versions of the present book from the latest versions of MiKTeX[1] and Texmaker[2] in order to produce a pdfLaTeX output. Moreover, in order to avoid reencoding all previous files of the French original I had to enter Chinese characters from their Big5 encoding. Consequently, a rare Chinese character, whose *pinyin* transcription is *chong* and which is used in the name 'Zu Chongzhi' was not available. However, I could replace it by an homophone, 沖, having a nearly identical graph: it has merely one dot in excess on its left part which should be removed in order to obtain the missing character.[3] Moreover, for the same reason, some Japanese words have been reproduced from their ancient forms. However, the correspondence with those now in use can be easily retrieved from current dictionaries.[4]

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[1] `http://miktex.org/`.

[2] `http://www.xm1math.net/texmaker/`.

[3] The three Chinese characters used in this book for 'Zu Chongzhi' are the following: 祖沖之.

[4] For instance: Nelson, A.N., *The Modern Reader's Japanese-English Character Dictionary*, 2nd Revised Edition, Charles E. Tuttle Company, 12th printing, 1981.

INITIAL FOREWORD

This purpose of this book is to highlight some of the most fundamental mathematical structures underlying the calculation techniques used for the construction of the Chinese historical official calendar, in a way that makes it possible to efficiently determine its main elements over as large a number of years as possible, from a preliminary description of its invariant structure. Apart from technical matters, however, great importance has also been granted to the wider context of this mathematics, particularly its epistemological aspect, which is so important in order to understand its nature, purpose and function.

Unofficial Chinese calendars and non-Chinese calendars currently also used in China, such as the sinicized Muslim calendar, are not included in the present study for the following reasons: we wholly ignore the calculation techniques of the former whereas the latter rely on mathematical techniques utterly different from those of the Chinese calendar.

The historical period retained spans the years of the interval 104 BC–AD 1644, a choice dictated both by the state of manuscript and printed sources handed down to us and by the overall unity of Chinese calendrical calculations developed between these two limits, extending over more than seventeen centuries.

In the case of more ancient years, we do not possess any historical document explaining calendrical calculations while, on the contrary, numerous and detailed treatises are available for most years posterior to 104 BC.

From 104 BC to AD 1644, Chinese calendrical calculation techniques have never ceased to belong to the same family, for they have always been designed in the form of lists of procedures, always formulated and organized in the same way. Overall, calendrical events are mostly dealt with like those of astronomy by only seeking to obtain the best possible precision, irrespective of their unceasingly variable underlying techniques. No less characteristically, the modes of representation of numbers and the technical terminology they rely on are eminently unstable; they also assign arbitrary patterns to numbers by taking avail of numerological correlations.

By contrast, the period following the year 1644 marks a break with previous traditions: the reform of Chinese astronomy then undertaken successfully by Jesuit astronomers has resulted in a dependency of Chinese calendrical calculations on techniques previously unheard of in China – trigonometry, geometry, logarithms, ... – used in Renaissance Europe and directly in line with Greek mathematics and astronomy. Hence a discontinuity between former and newer Chinese practices which would doubtlessly deserve a study in its own right. Yet, when certain features of Chinese calendrical calculations from this later period can clarify older practices for one reason or another, we have not ruled out comparisons.

Although, as already noted, official Chinese calendrical and astronomical techniques developed between 104 BC and AD 1644 belong to the same family, its members are extremely numerous and seemingly far apart from each other: in the intervening years, they have been unceasingly reformed no fewer than fifty times. Nothing of the sort exists anywhere else than in the Chinese world.

In order to highlight the main structures organizing this wealthy repository of mathematical techniques, the following approach has been retained:

First, noting that the backbone of the Chinese official calendar has remained identical to itself over time, we have attempted to highlight its invariant structuring principles and ideas.

Second, we have deliberately chosen to formulate in as general a way as possible the abstract techniques underlying Chinese calendrical calculations and the numerical results they lead to. By contrast, their profuse philological and syntactic peculiarities have not been our priority, even though this aspect of the question is certainly also of primary importance for other purposes. Given the inchoative state of this field of study, however, practically everything remains to be done, even when taking into account the always increasing number of specialized publications. Therefore, the need to clarify the general structure of calendrical calculations has seemed more pressing than a study focusing on the exploration of the quasi-tropical jungle of its specific linguistic manifestations. Nevertheless, such questions have been highlighted when it was obviously desirable to take them into account.

After numerous tentative steps and false trails, we have elaborated a first version of a technique for describing Chinese calendrical calculations from a limited set of ad hoc notions and notations.

Thanks to this tool, it turned out that only a limited number of such techniques exists, modulo a residual number of recalcitrant processes, either seemingly difficult to gain access to because of the incomplete character of Chinese sources or their apparent obscurity, mainly. More precisely, Chinese calendrical techniques fall under two fundamental types: those relying on mean elements and those admitting both mean and true elements, these two notions having their usual astronomical meaning.

On this basis, we have fully described the structural core of all the techniques of the first type and sketched an outline of the second ones, so that it became easier to figure out the overall rationale of the innumerable techniques used to calculate Chinese official calendars from 104 BC–AD 1644.

Hence, also, the conquest of a sort of autonomy enabling us to perform Chinese calendrical calculations in various but equivalent ways, recorded or not in original sources. It follows therefrom that it is not always necessary to follow original procedures to the letter in order to obtain exactly the same results, to grasp their scope, to deduce some of their consequences and to provide answers to, notably, the following questions:

- Is a calculation technique so obtained sufficient in order to restore exactly the content of authentic Chinese official calendars?
- Is it generalizable?

Although the small number of extant authentic calendars issued between 104 BC and AD 1644 precludes the possibility of giving a final and general answer to these questions, it remains that once a calculation method has been formulated, its becomes possible to determine the putative content of Chinese official calendars, even in the case of years for which authentic calendars are not extant. Hence the possibility to retrieve the theoretical dates of a large number of calendrical events, well beyond the most fundamental ones listed in available tables of the Chinese calendar and concordance tables. But, of course, this is not always possible in all cases if only because not all Chinese calendars have been obtained only from calculations but also from political decisions.

Beyond reconstructed calendrical dates, it is sometimes also possible to deduce completely and globally the general structure of calendars obtained from certain types of procedures, notably those based only on mean elements.

Furthermore, the practice of these calculations shows that the modes of representation of numbers used in calendrical calculation – and more generally in all Chinese astronomical canons too – are unexpectedly not based on decimal representations. Moreover, it also happens that number representations also rely on a particular form of written zero, practically never mentioned by historians of mathematics. It is of course hardly necessary to stress the importance of these two results which are of interest not only for the history of the Chinese calendar and astronomy but also, more broadly, for the history of mathematics since they drastically challenge the usual idea that, over its very long history, China would have been only aware of nothing else than a decimal and positional system of numeration, any other possibility being ruled out.

In order to present these results, the present work has been divided into three parts:

The first part expounds the principles on which this study is based. Then a presentation of the history of the Chinese calendar follows, both from the perspectives of its specific content and calculations, together with related questions of interest, such as a list of all irregular years of the Chinese calendar.

The second part focuses on the fundamental technical, mathematical and astronomical aspects essential to any description of Chinese calendrical calculations: the representation of numbers and numerical constants, astronomical and non-astronomical, the question of the determination of the origin of time and other technical notions peculiar to lunisolar calendars, such as the lunisolar shift, or epact, and the rule for determining intercalary months. On this basis, the details of particular techniques of interest in the calculation of the Chinese calendar are tackled by distinguishing those using either mean elements, true elements or both sorts of elements. Then, two little known elements of the Chinese calendar, namely the *Mo* 沒 and *Mie* 滅 days, are introduced with a wealth of details because they tend to prove the influence of Indian culture on the Chinese calendar.

The third and last part contains some examples of fully developed calculations for calendars of given years, their results being compared, when possible, with the content of authentic calendars and when not, with the calendrical data listed in chronological tables of the Chinese calendar. In addition, a large number of examples of specific calculations are provided everywhere in the main text.

Thereafter, a series of appendixes also provides systematic tables giving lists of numerical constants indispensable when performing calendrical calculations, together with a chronological list of Chinese official astronomical canons.

Lastly, the bibliography of primary sources presents the most important references concerning both the study of the Chinese calendar, its calculations and Chinese chronology. In its turn, the bibliography of secondary sources contains an extensive list of publications in Chinese, Japanese and Western languages.

Chinese calendrical calculations in general constitute a vast domain. However, they represent only a minute fraction of the wider domain of Chinese mathematical astronomy. So far, however, this astronomy has often been regarded as reducible to a purely qualitative science, based on an accumulation of precise observations and no mathematics, contrary to the other great astronomies from Antiquity and the Middle Ages.

If, by stressing the role of mathematics with respect to the limited domain of Chinese calendrical calculations, the present work can encourage historians of science and sinologists to take a greater account of the eminently mathematical character of traditional Chinese astronomy, our objective would have been achieved.